Multidisciplinary Analysis of Segmented Reflector Telescopes

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ABSTRACT

This paper is a summary of the work presented in the video tape demonstrating the integrated modeling capabilities that exist in an analytical tool being developed at JPL called IMOS (Integrated Modeling of Advanced Optical Systems). A segmented reflector telescope, whose performance is based on structural, controls, thermal, and optical disciplines was analyzed. The segmented reflector telescope model is a segmented mirror Cassegrain telescope system. The analysis completed here uses a two-ring, 18 segment primary mirror and a telescope wi(h a 3.75 meter aperture. The system is f/1 O. The primary mirror support truss is a tetrahedral structure. The primary mirror support truss is parabolic in shape. The primary mirror segments are hexagonal. The secondary mirror is attached to the outer ring of the primary mirror support truss by a 3 rod spider support. Each of the segments is positioned by 3 linear actuators with lateral restraining flexures. Dampers are added to the telescope primary mirror support structure [0 attenuate the effects of the structural disturbances. The damper locations are chosen based on optical design variables and performance metrics and structural performance metrics.

Several types of analysis were demonstrated in the video. Animation capabilities included telescope slew and settle simula ions. The cumulative effects of external model disturbances on the imaging of the telescope were included. Uncompensated therms" distortion can also significantly degrade the imaging capability of the system and were demonstrated. Disturbances exciting natural modes of the structure can also adversely affect the optical quality of images and examples were provided. Comparison of image resolution for various damping struts configurations in the primary mirror support structure were shown, including a comparison of results obtained with the different (optical vs. structural) performance metrics.

The numerical work is baseduponthe computer tool IMOS (Integrated Modeling of Advanced Optical Systems) being developed at JPL. The examples will be worked in the IMOS prototype environment based upon Pro- Matlab and the JPL Controlled Optics Modeling Package (COMP). This provides the integrated environment for analysis of controlled structures which support high performance optical systems. Portions of the work done in this paper were completed under the CSI (Controls/Structures interaction) technology project. The paper describes many examples of [he type of work that can be completed and demonstrates the advantages of using an integrated environment.

INTRODUCTION

The integrated modeling and design capability utilized in this paper is being developed at JPL under funding provided by the JPL Director's Discretionary Fund and the JPL Control/Structure Interaction Program (CSI). The computer programs provide an unprecedented capability for integrated modeling and design of systems. The engineering disciplines supported include structural dynamics, controls, optics and thermodynamics. Excellent graphics/plotting capabilities exist in the tool. These tools are needed to evaluate the end-to-end system performance during conceptual design. The graphic s/plotting capabilities facilitate both model building and understanding of analysis results.

The IMOS Integration Workbench is a collection of Pro-Matlab functions to model structural dynamics by the finite element method and to integrate. these models with COMP optical models. The 'different models are assembled in Pro- Matlab where the spacecraft's end-to-end performance can be analyzed and trade studies conducted to design the system. Interactive exploration of system performance is supported by 3-D graphics for viewing the models and 2-D engineering graphics for plotting performance, The finite element capabilities include dynamics using rods, beams, plates, and concentrated masses, and additional functions to generate thermal expansion forces. The dynamics equations are formulated in first order from which enables application of all the inherent Pro-Mat lab equation solution, eigen solution, frequency domain and time domain simulation functions.

COMP is a st:in(i-alone FORTRAN program for analysis of optical systems. In COMP, a collection of optical elements is modeled as conical surfaces, surfaces tiled with hexagonal segments or refractive lenses. A mesh of rays, described by the user in the system input

plane is propagated through the train of optical elements. COMP capabilities include mirrors and lenses with flat, conic, 10th-order asphere, Zernike, or data defined surfaces, and deformable mirrors. Collimated and point sources with uniform or Gaussian profiles are included. Also included are segmented mirrors, non-sequential mirrors, lenslet arrays, and pixilated (digital) detectors. Both geometric propagation anti diffraction propagation arc support eel. Geometric ray-trace optics include spot diagrams, wavefront error (Optical Path Difference), beamwalk, and ray direction. Differential ray-trace optics include surface-to-surface or exit-pupil (diffraction, point images, pupil intensity maps, multiple wavelengths, multiple source images, and pixilated intensity, amplitude and phase. Since COMP is intended to be used with structural dynamics modeling systems, methods are provided to compute the sensitivities of the optical system to perturbations in the element positions and orientations.

BODY OF REPORT

Description of Segmented Reflector Telescope (SRT) Model

SRT is a segmented reflector telescope model (see Fig. 1). The model is parametrized and many of the critical parameters such as the mirror focal lengths, number of rings, and size of the mirror segments can be modified by changing only one variable. A new model can then be generated in less than one minute. (see Fig. 2)

Modal cost

Dynamic disturbances impact the optical quality of the telescope. Two typical vibration modes that occur when the telescope is attached to a ground pedestal are shown. The 15 Hz fundamental mode is a rocking mode. A 47 Hz mode is a rocking mode. The disturbed pierce points of the optical rays (spot diagrams) corresponding to the maximum deflection of the modes are shown for each mode. (see Fig. 3)

Thermal Variation Cost

An on-orbit thermal gradient across the primary mirror truss structure is a quasi-static disturbance applied [0 model with free-free support conditions which will affect the performance of the telescope. The sun side of the primary mirror support structure is 166 degrees Kelvin and the shaded side of the primary mirror

support structure is 143 degrees Kelvin. This causes the structure to expand and contract, distorting the primary mirror segment locations. The impact of this distortion is also demonstrated with a spot diagram. (see Fig. 4)

Optimization/Dampers

The ability to vary structural and optical parameters in IMOS enables multidisciplinary optimization of the thermal, optical, and structural designs. The problem we chose is to attenuate structural motions that diminish optical quality, Two different criteria were chosen. The first set of damper locations was chosen using a traditional criteria to indirectly improve optical quality by minimizing the RMS deflections of the primary mirror support structure. The second set of damper locations was chosen using a multidisciplinary criteria to maximize the optics intensity. The different damper locations are shown (see Fig. 5) The multidisciplinary optimization leads to a different and optics ly superior damper locations.

Slew and Settle

When a telescope is in space, it is desirable to maximize the percentage of time spent actually observing science targets such as stars or planets. It takes time for the spacecraft to slew to the new observing area and find the star. Once the star is found, it takes time for all the vibrations of the spacecraft structure to dic out, so a clear image can be formed with the telescope. This example demonstrates how the image comes into focus as the vibrations dic out. (see Fig. 6)

Reaction Wheel Disturbance Work

A spacecraft often uses wheels to control it's attitude. The reaction wheels must continually spin to maintain the correct attitude. As the wheels spin, they generate disturbances which affect the quality of images which can be obtained. This example demonstrates how IMOS can be used to evaluate and visualize image quality resulting from different designs. A much sharper stellar image is obtained when dampers are added to the truss structure. Shown below is a comparison of image quality for a typical exposure time for a structure without dampers and a for a structure with 6 passive dampers in the strehl optimized locations. (See Fig. 7)

Image Resolution Work

Imaging double stars places additional require.ments on telescope stability because of the c1osc proximity of the two stars. This example demonstrates how 6 passive dampers not only improve the intensity of the star images, but also the clarity of the different peaks. When no passive dampers are included in the primary mirror truss structure, the second, fainter star becomes indistinguishable as disturbances from the reaction wheels arc added to the model. (See Figs. 8 & 9).

Other Work Completed in IMOS

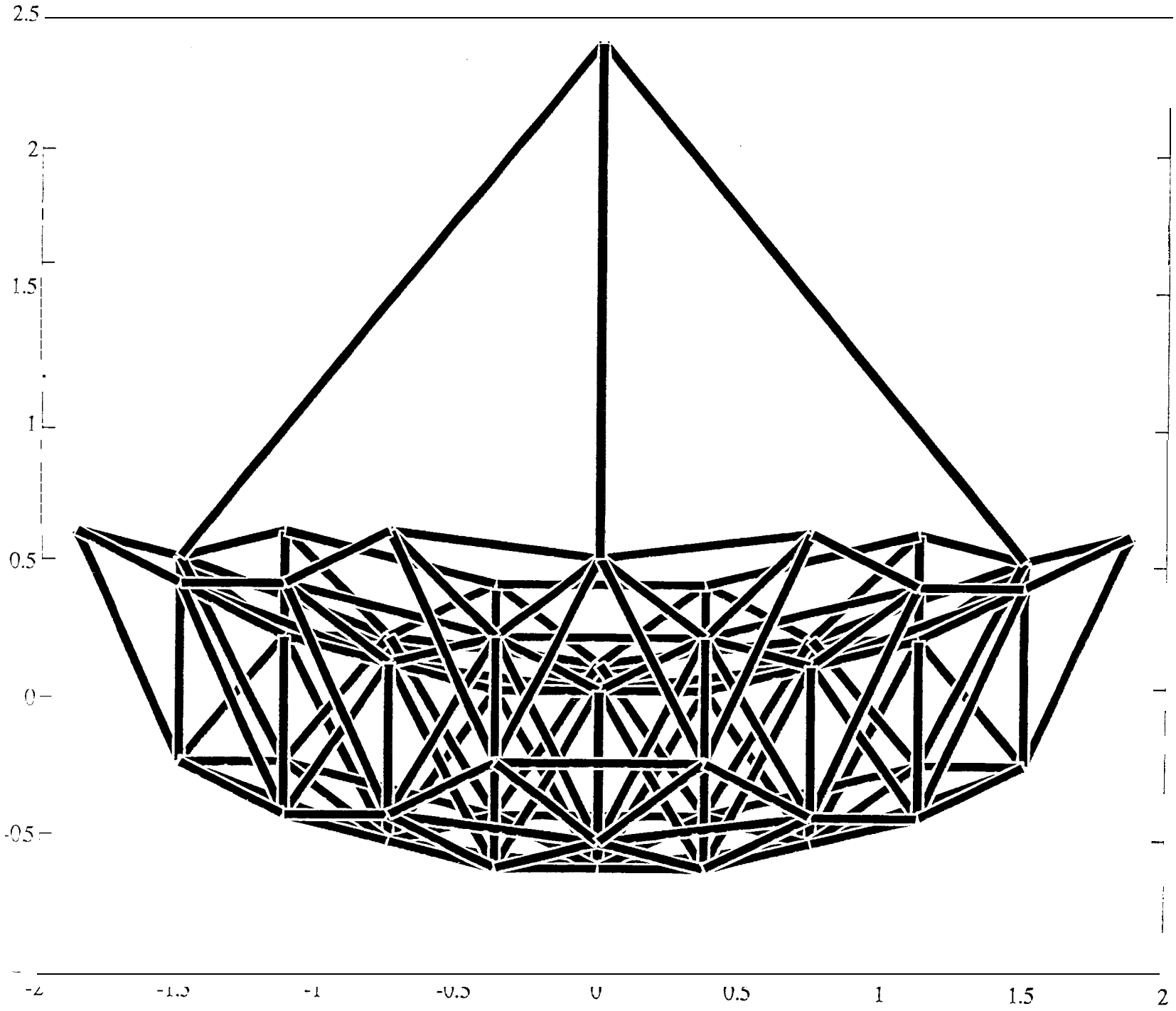
Other work completed in IMOS includes image inversion and prescription retrieval for the Hubble Space Telescope, background subtraction for sub-millimeter projects, laser metrology system calibrations for interferometers, and fine guidance sensor centroiding analysis for SIRTF.

CONCLUSIONS

Several examples of integrated analysis were demonstrated. IMOS provides a powerful tool for the analysis of telescopes under a variety of conditions. By combining structural, thermal, and optical simulation capabilities, one person can perform in minutes what used to require several people and days to complete. The graphical capabilities allow fast analysis of data and provide a physical interpretation of the results. Trade studies can be completed quickly, permitting rapid evaluation of options. Using IMOS, costly or impossible analysis and simulation can now be comple ted quickly and easily.

ACKNOWLEDGEMENTS

The research described in this paper was performed at the Jet Propulsion Laboratory, California Institute of '1'ethnology, under contract with the National Aeronautics and Space Administration.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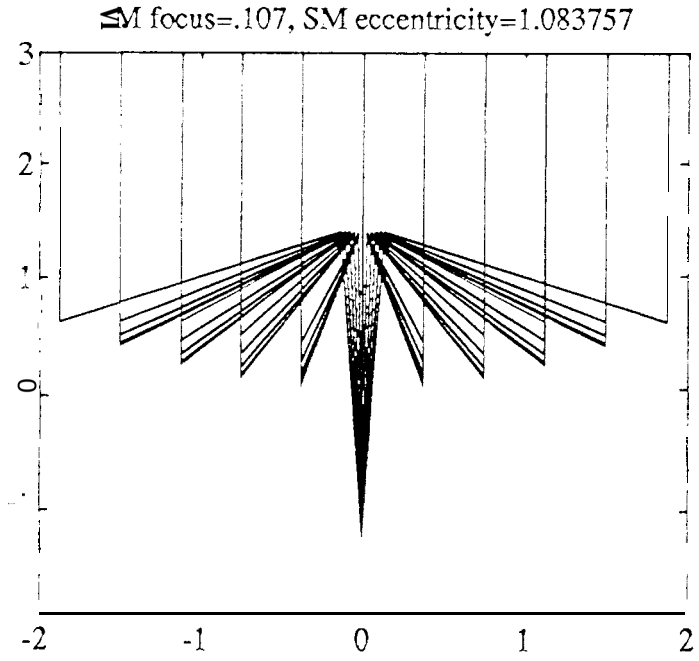
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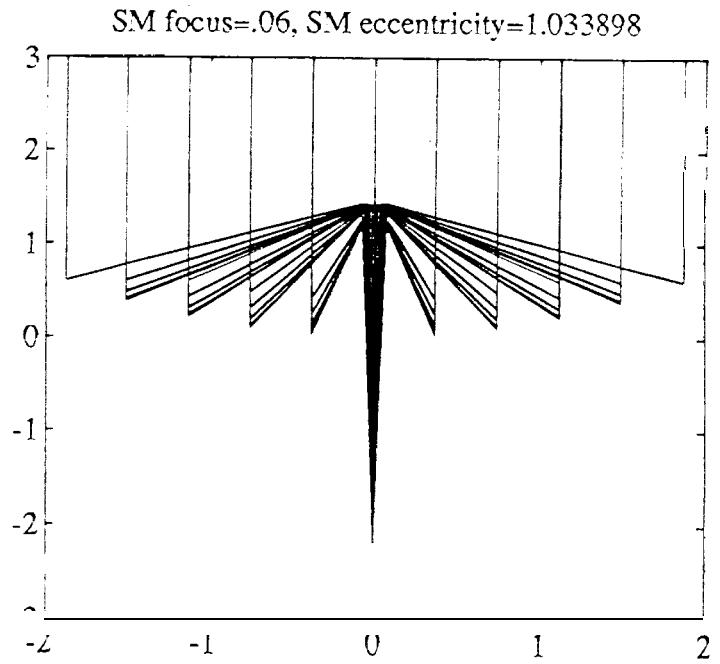
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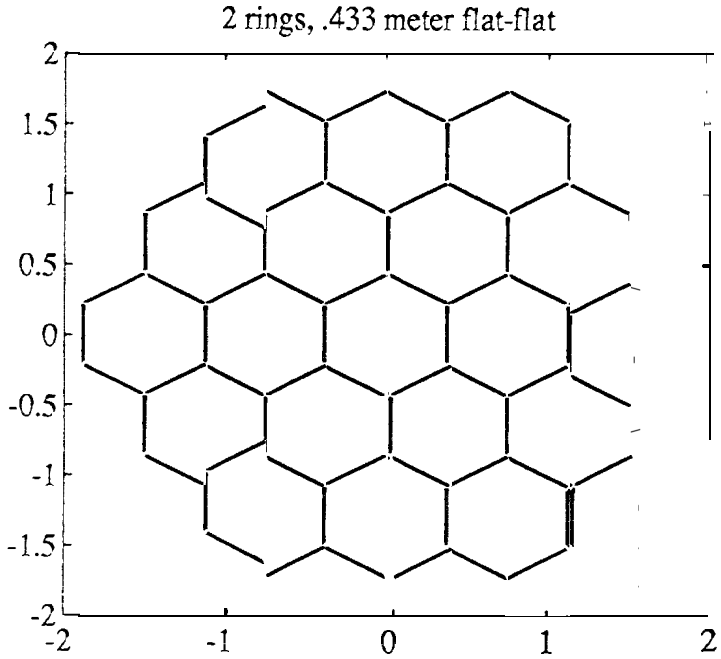
2 rings, .433 meter flat-flat
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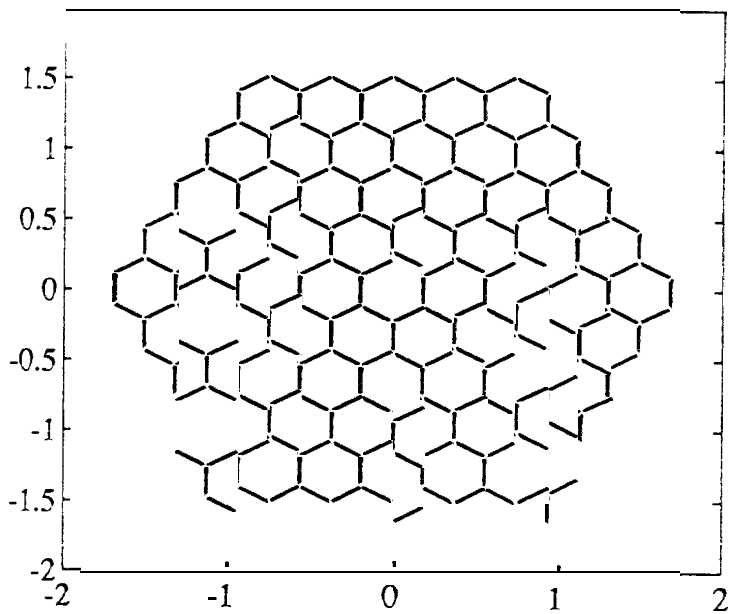
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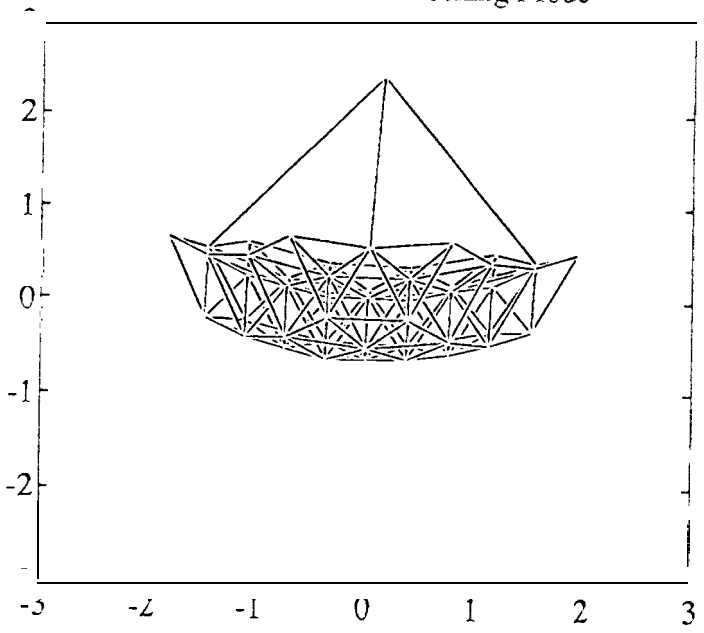
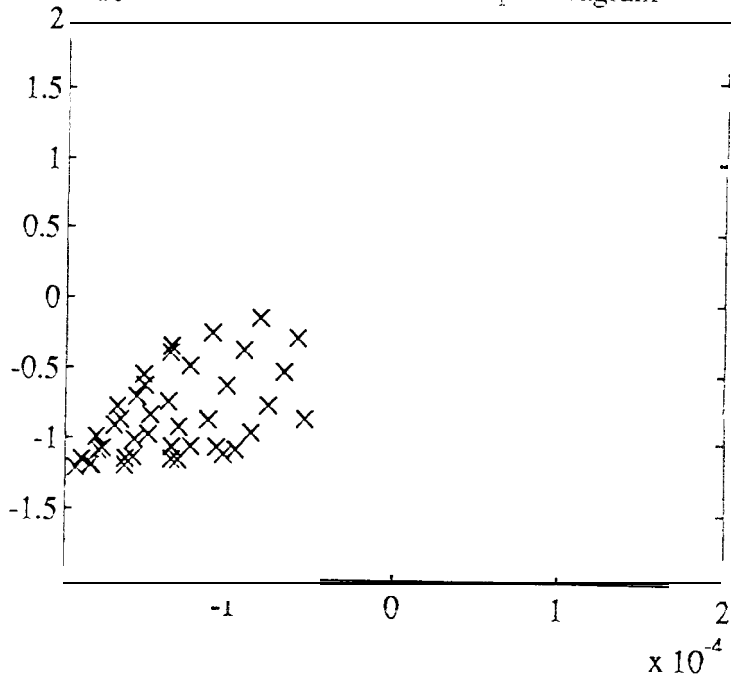
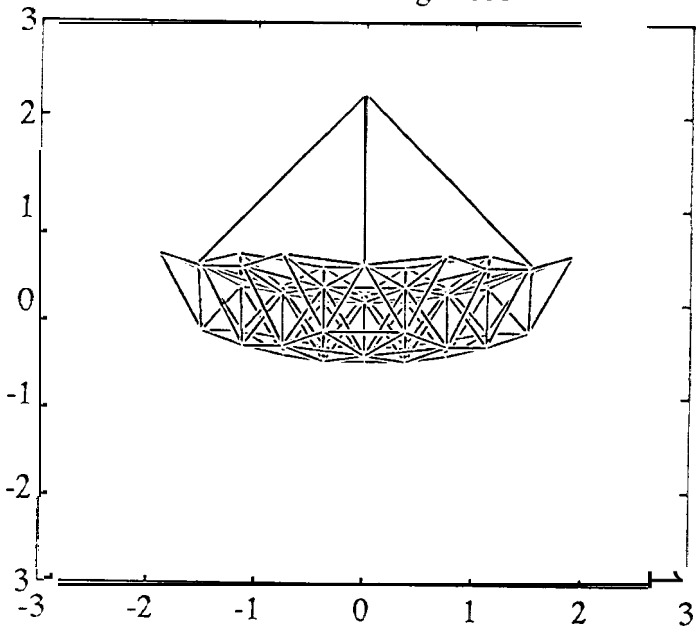
15 Hz Fundamental Rocking Mode

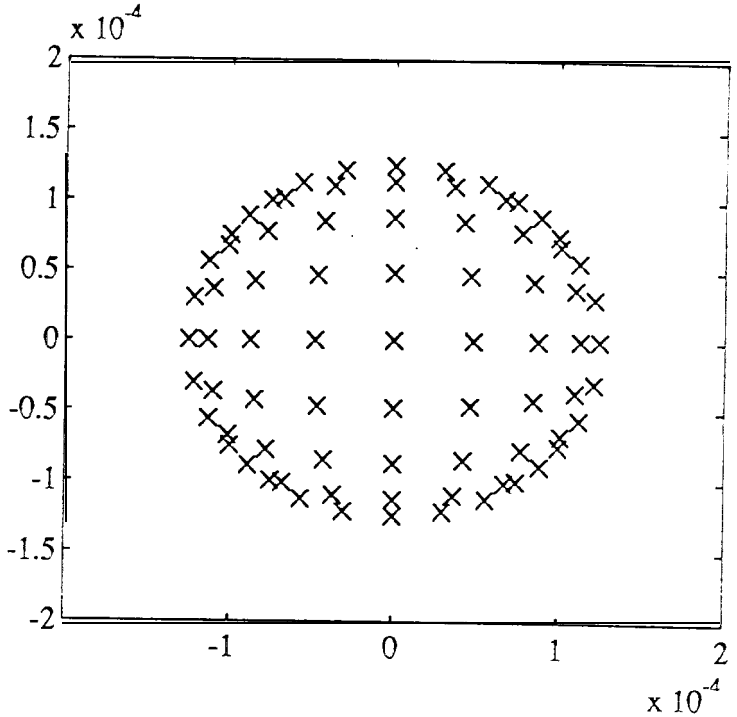


x 10^{-4} 5 Hz Fundamental Mode Spot Diagram

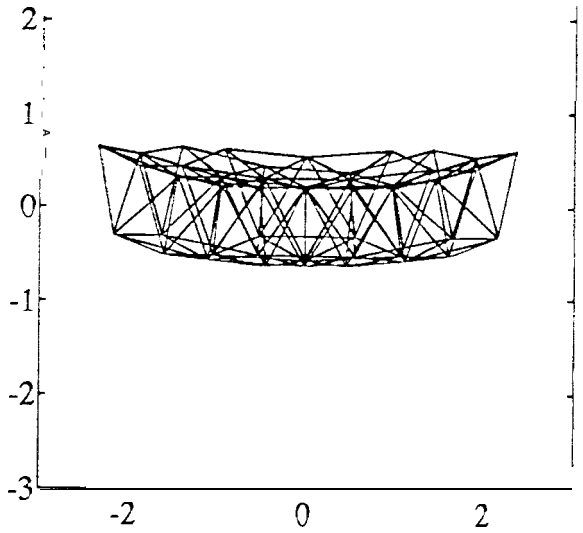


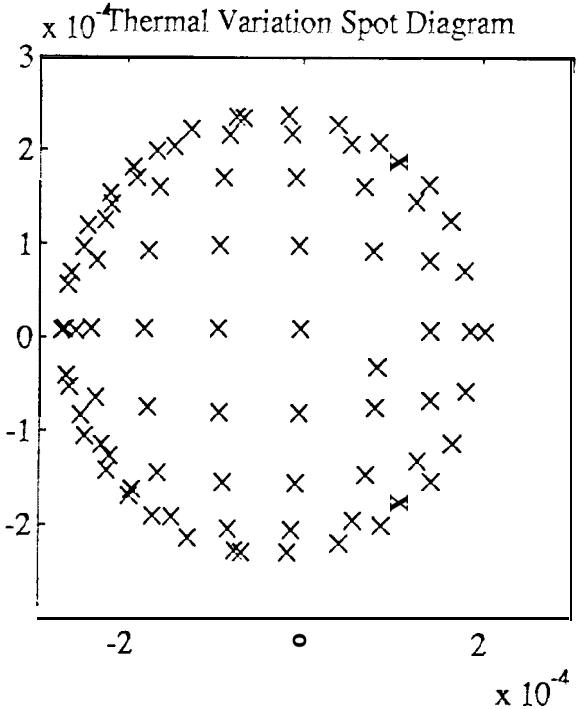
47 Hz Breathing Mode

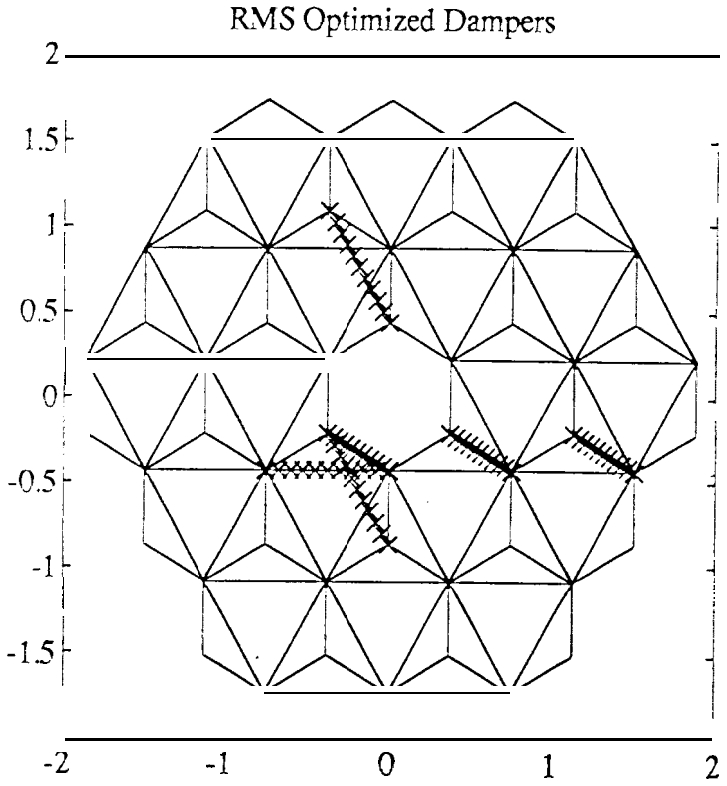




Truss Static Deflection on Hot Side, B 000



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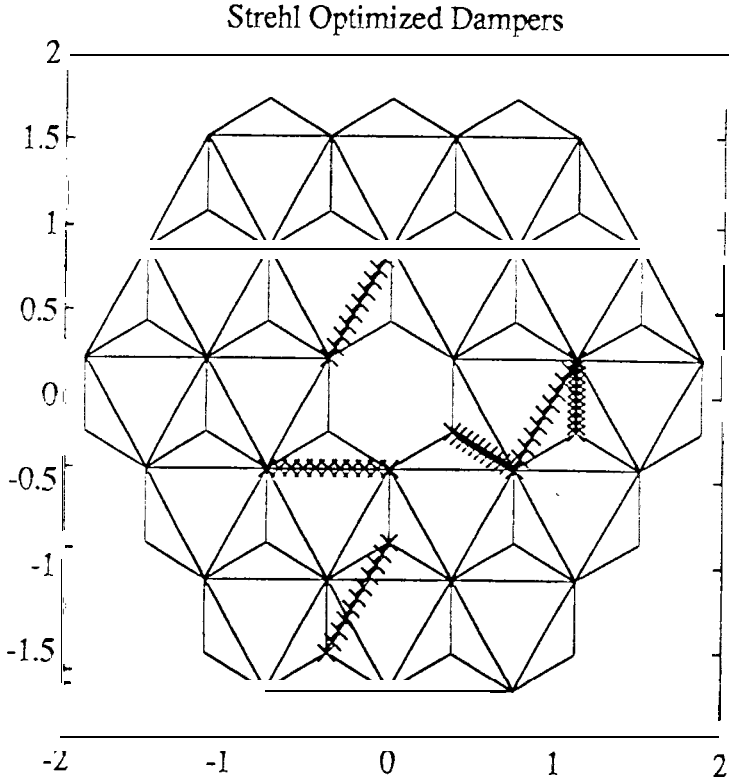
Strehl Optimized Dampers
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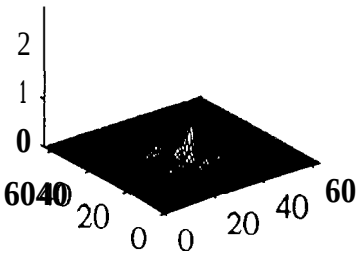
-2
-1
0
1
2

Beginning of the Settle
x 10-[8]



Decrease in intensity Ripples
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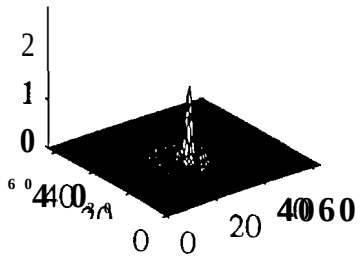

Increase in Central Intensity
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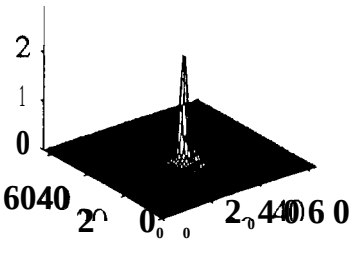

Peak Intensity
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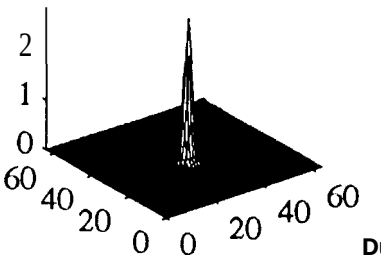

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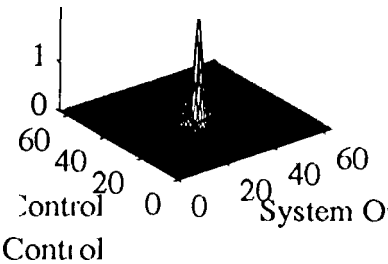
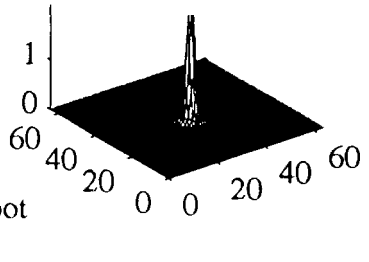
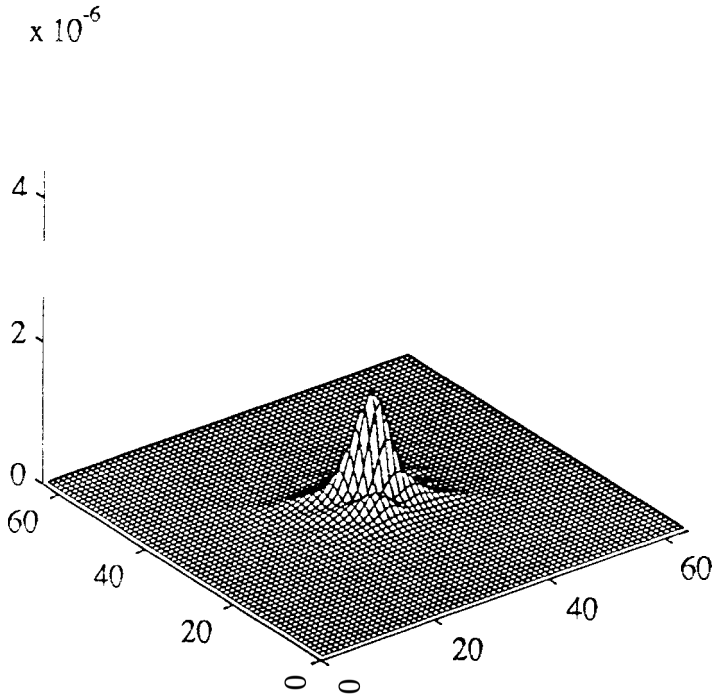


Peak Intensity - End of Settle
x 10-[8]

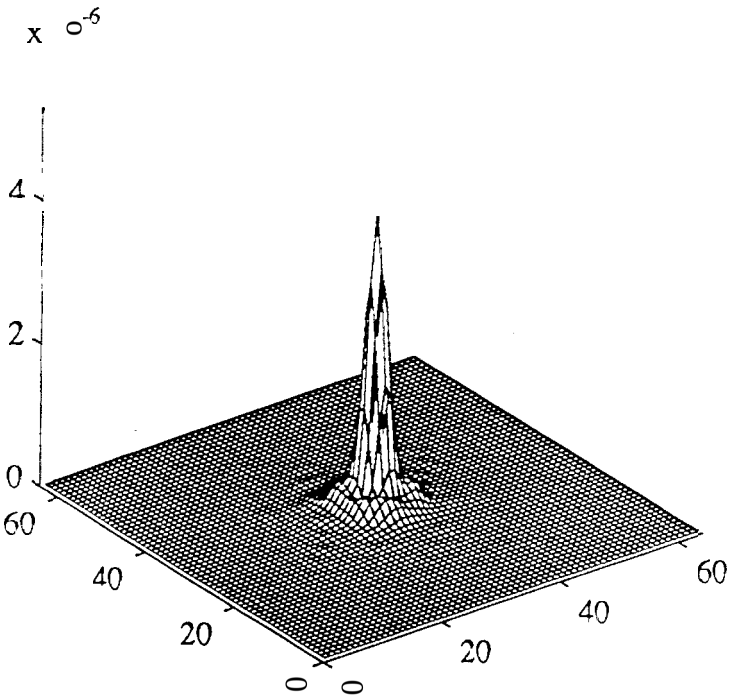


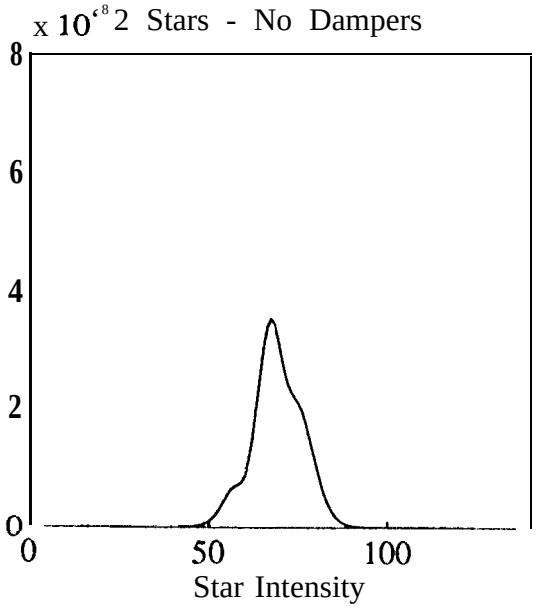
Control System Overshoot
Due to Control

RW disturbance No dampers



RW disturbance 6 passive dampers

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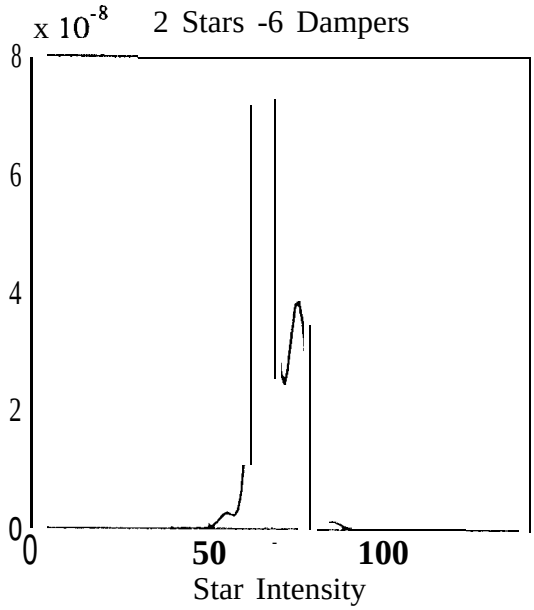
Star Intensity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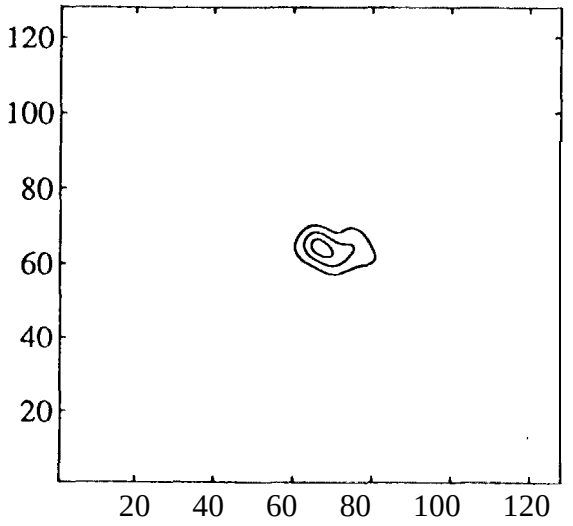
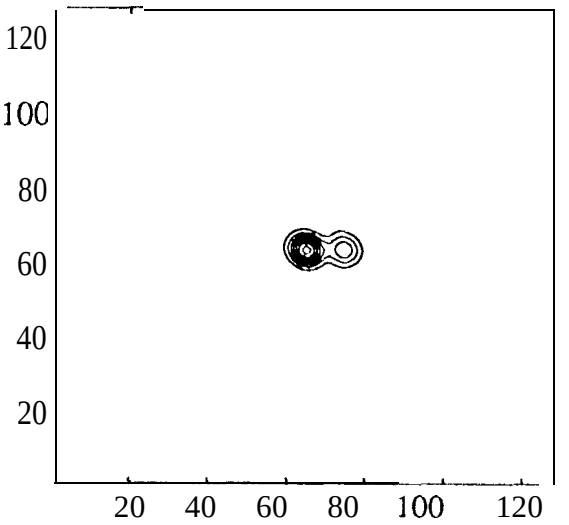
Star Intensity

2 Stars -No Dampers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